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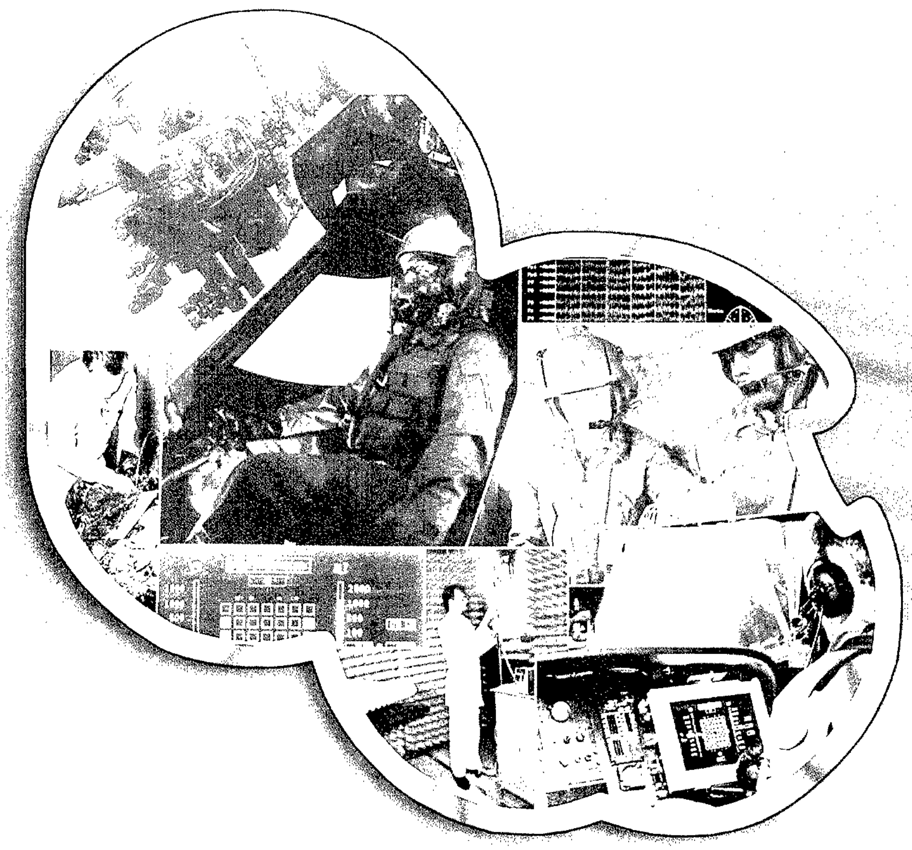
Diopter Focus of ANVIS Eyepieces Using Monocular and Binocular Techniques

by William E. McLean and Corina van de Pol



Aircrew Health and Performance Division

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US Army aviators were asked to obtain best resolution using an ophthalmic phoropter with three different focusing techniques, viewing with unaided vision and through the aviator's night vision imaging system (ANVIS). Eight participants were over 40 years old and 16 participants were less than 30 years old. The method labeled "Clearest" vision allowed the participant to oscillate the diopter lens powers to obtain best resolution in both positive (correction for hyperopia, and to reduce accommodation) and negative (correction for myopia, and to stimulate accommodation) lens power directions, monocularly. The "Maximum Plus" method instructed the participants to first blur the tri-bar target using excessive plus lens power to go past infinity and then change the lens powers towards the minus values just to clearest vision and no further using monocular vision. The "Binocular" technique involved blurring both eyes slightly with excessive plus lens power and then instructing the participant to reduce the plus lens power for one eye to clearest vision binocularly. The procedures were repeated with the other eye.

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Block 19. Abstract

The results showed that the "Binocular" focusing technique for best resolution induced less negative lens powers than the "Maximum Plus" and "Clearest" vision methods both with and without the ANVIS. The difference in the lens power between unaided and ANVIS best resolution focusing values was approximately –0.25 diopter with the ANVIS.

Acknowledgements

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Objectives

To determine the right and left eyepiece diopter focus values of ANVIS using three different focusing methods for young (under 30 years old) and older (over 40 years old) night vision goggle (NVG) aviators. To determine aviator's night vision imaging system (ANVIS) eyepiece range of lens powers in which the subject reports the clearest monocular and binocular vision. To compare subjective refractions through ANVIS to subjective binocular refraction values using green backgrounds (comparable wavelength to ANVIS). Note that this report uses a unit of lens and prism power called "diopter", which may not be familiar to the reader. Appendix A contains definitions and tables of lens and prism diopter values.

Military significance

The design of the next generation of NVGs called the Panoramic Night Vision Goggles (PNVG) or the Advanced Night Vision Goggle (ANVG) may use a fixed focus eyepiece with no user adjustment (Jackson and Craig, 1999) (Marasco and Task, 1999). Future helmet mounted displays may also use fixed focused eyepieces to reduce weight and complexity. Previous studies have shown that the optimum eyepiece focusing distance for clearest vision to accommodate most military aviators is closer than infinity. This study analyzed the eyepiece focusing distances for clearest vision using three different focusing methods and recommends the best diopter value for clear and comfortable vision to accommodate U.S. Army aircrew members for the ANVG program.

Background

An extensive literature review was conducted in 1994 and 1995 on night myopia, instrument myopia, and dark-focus relevant to night vision devices (Kotulak, Morse, Wiley, 1994) (Kotulak and Morse, 1994a, 1994b, 1994c, 1994d) (Kotulak, Morse, Rabin, 1995). Fifty-two references are listed in USAARL Report No. 95-35. Several studies have looked at the diopter values of the eyepieces of night vision goggles (NVG) when the subjects were using monocular focusing techniques (Kotulak and Morse, 1994b). Kotulak and Morse evaluated a monocular focusing technique, which is referred to as the "Maximum Plus" method (Antonio and Berkley, 1993). The subjects were 10 Army aviators and 3 Army flight students. For a 5.8-meters viewing distance (0.17 diopters), the mean eyepiece diopter setting was -1.13 diopters (D), ± 0.63 D standard deviation (stdev). The absolute value of the mean and stdev difference between the eyepiece focus of the right and left tubes was 0.57 D, (± 0.47 D). The study also showed that an infinity focus setting of the eyepieces for some of these subjects produced less resolution than the "user adjusted" condition. It should also be noted that the mean autorefractive error for these 10 pilots who were not required to wear corrective lenses for flight was -0.40 diopters.

A recent Air Force laboratory study evaluated the ANVIS eyepiece diopter settings for best resolution using operator adjusted eyepiece focus and fixed diopter values of 0.0, -0.50, -1.00, and -1.50 diopters (Gleason and Reigler, 2001). Twelve subjects (24 years +/- 6) participated

using the monocular "Maximum Plus" method of adjustment for the eyepieces. The results showed a mean eyepiece adjustment value of -1.05 diopters, stdev 0.34, range -0.25 to -1.75 diopters. Absolute mean difference between the right and left eyes was 0.40 diopters, stdev 0.29, range 0.00 to 0.75 diopter.

The characteristics of the target used for focus can also effect the detection of blur and therefore, the range of focus settings (Rabin, 1994). These characteristics include spatial frequency, contrast, and luminance.

A binocular focusing technique, which is commonly used for clinical subjective refractions, has been used by some of the Army aviators since the mid 1980's to focus the eyepieces of NVGs. However, this technique has not been formally evaluated and quantified with NVGs. A study comparing monocular and binocular focusing of microscopes showed that the convergence angle between the right and left image with binocular viewing had a strong relationship to the amount of induced accommodation (Schober et al. 1970) (Farrell and Booth, 1984). With the microscope convergence alignment set at infinity, the mean eyepiece settings using binocular criteria were less minus than any of the monocular focusing methods. The differences and variability in the NVG eyepiece adjustment values among the various focusing techniques (two monocular and one binocular) between and within subjects for the NVG aviator users have not been determined.

At least three different eyepiece focusing techniques have been published for NVGs. The procedure and principle for focusing one of the eyes with each of the three identified techniques is described below. To focus the eyepiece for the other eye, the procedure would be repeated with the instructions for the eye of regard reversed:

a. CLEAREST VISION- "Close one eye and adjust the other diopter adjustment ring for clearest view" (published in Operator's Manual, Night Vision Goggles, TM 11-5855-238-10, dated 1975, and updated 1980, and 1988; and Operator's Manual, Aviator's Night Vision Imaging System, TM 11-5855-263-10, dated 1983 and 1990). The principle for this technique is to obtain the clearest vision when viewing with one eye.

b. MAX PLUS- "Close one eye. Rotate eyepiece (back lens) for the other eye fully counterclockwise. Then rotate the eyepiece clockwise until just obtaining the clearest vision" (published in NVG Operations, Student Handout, 1991, Aviation Training Brigade, Night Vision Devices Training and Operations Facility, U.S. Army Aviation Center, Fort Rucker, AL). Variations of the MAX PLUS technique include the instructions "Place the eyepiece diopter setting at zero; cover one tube and keep both eyes open; rotate the eyepiece knob counterclockwise to first sustained blur; reverse rotation (clockwise) just to the clearest vision point and stop" (published in ANVIS Operator's Manual TM 11-5855-263-10, , dated March 1994). The principle behind the counter-clockwise rotation of the eyepiece is that when an image is first blurred using positive lens power (focused beyond infinity for nonspectacle wearers without a significant refractive error, a condition known as "emmetropia"), accommodation is relaxed before the eyepiece is focused for clearest vision. The objective of this technique is to

minimize stimulating accommodation and obtain the most positive relative lens power in the eyepiece with the best visual acuity.

c. BINOCULAR- "Slightly blur the objective (front) lens for one eye, closing or covering the other eye. Then, keep both eyes open, and focus the eyepiece (back lens) for the other eye to clearest vision" (published in NVG Operations, Student Handout, 1991, Aviation Training Brigade, and ANVIS Operator's Manual, TM 11-5855-263-10, dated March 1994). The principle of the binocular focusing technique is to use the eye alignment near infinity (parallel convergence) to control accommodation; thereby minimizing the differences between the accommodative and convergence distances.

In the CLEAREST VISION method, for an emmetrope, clear vision would be reported when viewing beyond 20 feet (far point without accommodation) to the limit of their accommodation or near point (max minus power). This near point in diopters is measured on routine flight physicals. If the person oscillates the focusing knob between these two far and near points of clear vision using one eye and then strives to find a midpoint, the eyepiece focus value will typically be a minus value and will stimulate accommodation. For a typical young aviator candidate with 20/20+ uncorrected vision, maximum plus power to first blur would be approximately +0.50 diopter, and the maximum minus power to first blur could range from -2.00 to -8.00 diopters (accommodation limits). Therefore, if the CLEAREST VISION method is used, the young user would typically focus between -1.00 to -4.00 diopters, which then requires a sustained accommodative effort similar to viewing objects between 1 to 0.25 meter (39 inches to 10 inches). With the MAXIMUM or MAX PLUS method, when viewing at 20 feet, a sample of 13 NVG users adjusted the eyepiece focus a mean value of -1.12 diopters or 0.9 meters (35 inches) accommodative effort with a standard deviation of 0.63 diopters (Kotulak and Morse, 1994b). The BINOCULAR NVG focusing technique has not been compared quantitatively to other focusing methods.

Regardless of the eyepiece focusing value, the image seen by the NVGs is angularly aligned (convergence angle between the right and left eyes) at the actual viewing distance, which would typically be beyond 20 feet to infinity. The Air Force, Navy, and even some Army NVG pilots are not using the BINOCULAR technique for the eyepiece focus. Several Navy pilots reported disturbances in their depth perception after wearing NVGs (Sheehy and Wilkinson, 1986). We believe that the pilots may have induced excessive minus power in the eyepieces and/or induced an imbalance between the eyepieces relative to the residual refractive error of each eye using monocular focus techniques. This means that the operator would have placed the accommodation (focusing) point at a different optical distance than the convergence (alignment) distance for both eyes, and/or the focusing points at different distances for each eye. The literature also suggests that some pilots may be having difficulty with their stereopsis while wearing the goggles if the residual difference in over- or under-correction after focusing between the two eyepieces is greater than 0.50 diopters (Simpson, 1991) or 1.00 diopter (Griffin et al., 1992).

For future helmet mounted displays (HMDs) and NVGs a fixed eyepiece focus has been proposed to reduce weight and complexity, and reduce misadjustments by the users. Infinity focus setting for the NVG eyepieces has resulted in less than the best visual acuity for some aviators who may have small refractive errors, but are not required to use lenses for flying. Acceptable spherical refractive errors for pilot candidates with uncorrected vision of 20/20 range from +1.50 to -0.25 diopters. Some suggested values of a fixed focus setting for HMDs and NVGs by visual researchers have ranged from 0.00 to -1.00 diopter, with no agreement on a specific value.

With HMDs used for daytime in a similar manner as head-up displays (HUDs), any lens power for the symbology different than that seen through the canopy will place the virtual image at a different focal distance than the real image, and reduce any simultaneous real and virtual image processing. Therefore, there is a strong argument for using infinity or near infinity focus for daytime viewing with HUDs and HMDs. However, instrument and night myopia from night imaging systems may suggest that the optimum eyepiece focal power may be significantly different than the focal distance for overlaid day symbology.

Methods

Approach- In previous studies, the user NVG eyepiece diopter power settings were measured with a diopter scope (dioptometer) and/or estimated from the diopter scale on the ANVIS eyepiece. Unfortunately, the ANVIS eyepiece scales are not very accurate and have shown between 0.50 and 0.75 diopter of hysteresis. For the experimenter to use the diopter scope for eyepiece measurements, the subjects would either have to move their heads from viewing the ANVIS, if the ANVIS were table mounted, or the ANVIS would have to be removed from their helmets and remounted for each trial so that the experimenter could take the measurements. Also, the diopter scopes that have 0.12 diopter sensitivity only have a $\pm$ 1.00 diopter range, which means auxiliary lenses are required for the expected values beyond -1.00 diopter.

For the unaided focusing trials, a green filter was added to an ophthalmic acuity projector, which simulated the green color from the ANVIS (Appendix B). The projector illuminated an Air Force tri-bar resolution chart and was adjusted to produce approximately 1.3 foot-lamberts (fL) luminance intensity for the white background.

To minimize the time to obtain repeated ANVIS eyepiece lens powers within 0.25 diopter and without the subjects having to change their position or viewing direction, we mounted an ANVIS in front of a low profile B&L "Greens" phoropter (see Figure 1). The ANVIS used was an ITT model F4949 with OMNI IV image intensifier tubes. The ANVIS eyepieces were focused to infinity with the diopter scope and the objective lens to the distance of the eye lane. The participants could then make all eyepiece focus changes and adjustments rapidly and accurately with the phoropter without changing the focus position of the ANVIS eyepieces or objective lenses. Eyepiece diopter values measured before and after the focusing trials showed a difference no greater than 0.12 diopters from the infinity setting.

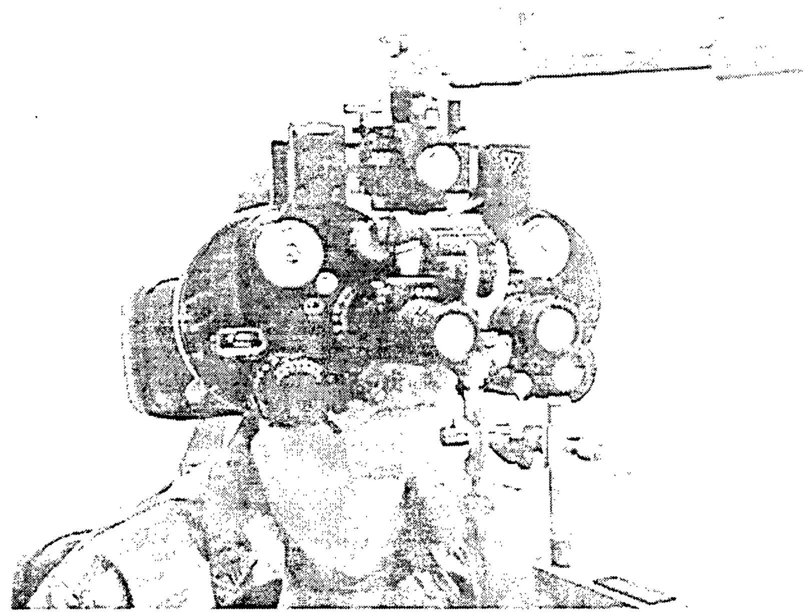

Figure 1. ANVIS in front of B&L phoropter for eyepiece diopter values.

For the ANVIS focusing trials, the Air Force tri-bar chart was illuminated with an overhead incandescent light that was adjusted with a variable resistor until the automatic brightness control (ABC) circuit in the ANVIS power supply was just activated. The Air Force tri-bar high contrast resolution chart under simulated high night illumination was used to minimize the variability of the focusing diopter values and maximize the resolution through the goggles. Low contrast, low spatial frequency (big) targets and low illumination to the eye would have reduced the minimum noticeable blur points.

The beginning sequence for with- and without- ANVIS and the two focusing procedures (max plus and binocular methods) were balanced among the subjects. Note that the "clearest vision" method was always determined before either the "max plus" or the "binocular" method. The subjects repeated each procedure three times to determine a median value. Using the median value, a lateral phoria was measured. The "plus lens power to blur" was determined monocularly, beginning at -0.50 diopter, and the end point was based on when the subject could not see the spacing between the three bars for an element that was two steps above (1.26 times larger) their best monocular resolution. The "minus lens powers to blur" end points were determined both monocularly and binocularly with the participants viewing two elements larger than their best resolution criteria. The diopter start point for the minus to blur procedures was 0.00 diopters.

Subjects: The NVG pilot population ranges from the student pilot to the presbyopic aviator near retirement age. Since two of the three focusing methods are designed to provide the most resolution with the least amount of stimulation to accommodation, young subjects (less than 30

years old) should show greater differences between the focusing techniques in the amount of induced accommodative than older subjects. Therefore, we used 16 student pilots aged less than 30 years old and 8 NVG instructor pilots over 40 years of age.

Procedures: Volunteer subjects were briefed on the study and requested to sign the volunteer agreement affidavit, if they wished to participate. Appendix E includes the data sheets used for this study.

Subjects were initialed screened using the Armed Forces Vision Tester to determine if they met current flight standards according to Army Regulation 40-501. The screening procedures included a determination of distant resolution, stereopsis, and phorias (lateral and vertical) using corrective lenses if required for flight duties. Following the screening, subjects received a manifest refraction (without dilation) to determine their spherical equivalent lens power using the bi-chrome test. Best visual acuity with the maximum plus lens power was determined when the resolution in the green background was just clearer than the resolution in the red background. Lateral phorias were measured at 6.7 meters and at 50 centimeters, with and without lenses to alter accommodation by 1.00 diopter. All testing was completed with the subject's refractive correction in place.

To minimize the effects of learning on a typical Snellen or Bailey-Lovie acuity chart and to minimize the time to determine best acuity, we trained the subjects to use the Air Force 1951 tri-bar high contrast resolution chart, which is a standard in the electro-optical testing field. Note in the "DATA FORMS" that acuity was assessed 48 times per subject, so hard copy resolution charts using letters would be easily memorized during best resolution determinations, with and without the ANVIS. The criteria for best resolution with the tri-bar chart was the smallest element that the participant could distinguish three separate bars for the vertical and horizontal components. Tri-bar best resolutions are typically less than Snellen acuity by a factor of 0.70 (Farrell and Booth, 1984).

Before beginning each trial and each focusing procedure, the investigator inserted a spherical lens power into the phoropter that ranged from +0.75 diopter to -2.50 diopters. These random values were determined with a computer and were based on the eyepiece diopter scale values found at a local Army training airfield from 20 pair of operational ANVIS. The B&L phoropter has a distinct click and tactical feel when the spherical power wheel is moved from the zero to –0.25 D positions. Therefore the +2.00 retinoscopy lens was added in the phoropter, which produced a resultant zero power (0.00D) with a –2.00 D wheel position without the click and tactical feeback to the participant. The odd numbered subjects always began each trial with their right eye and the even numbered subjects began with their left eye.

For the three different focusing procedures, with and without the ANVIS, the subjects changed the spherical lens powers in the phoropter and selected the end point for each eye using the procedures designated by the examiner. The time to complete the study for each subject was approximately 2 hours.

Results

Screening: All of the under 30 year old and over 40 year old participants met the Class 2 flight physical standards for vision. Of the eight over 40 year olds, seven were required to wear corrective lenses for flight duties. Of the sixteen under 30 year olds, only 2 were required to wear corrective lenses for flight duties. General statistical data on the participant's age, NVG hours, spherical equivalent for the manifest refraction, phorias without and with a -1.00 spherical lens, and monocular accommodation are located in Appendix C.

Right eye versus left eye: The data were initially analyzed to determine if there were any statistical differences between the lens powers for the right and left eyes for each procedure, condition, and age group using the t-test, two tail, with unequal variance method. Appendix D presents p-values for these comparisons between the means of the right and left eye diopter values. Since there were no significant differences between the right and left eyes values for all procedures, the data for the right and left eyes were averaged for plotting and further analysis. The absolute diopter differences between the left and right eyes for each procedure are reported later in this section.

ANVIS eyepiece focus: As expected, the binocular focusing method showed the least minus or negative lens powers to stimulate accommodation than did the monocular techniques of Maximum Plus and Clearest Vision. However, these differences were smaller with the older group with reduced accommodation than with the younger participants. Figure 2 shows a sorted distribution of eyepiece diopter values averaged between the right and left eye versus percentile for the three different focusing techniques with ANVIS for the under 30 and over 40 year old groups. Note that the solid lines data points represent the over 40 group and the dotted lines and open data points are the under 30 year old group.

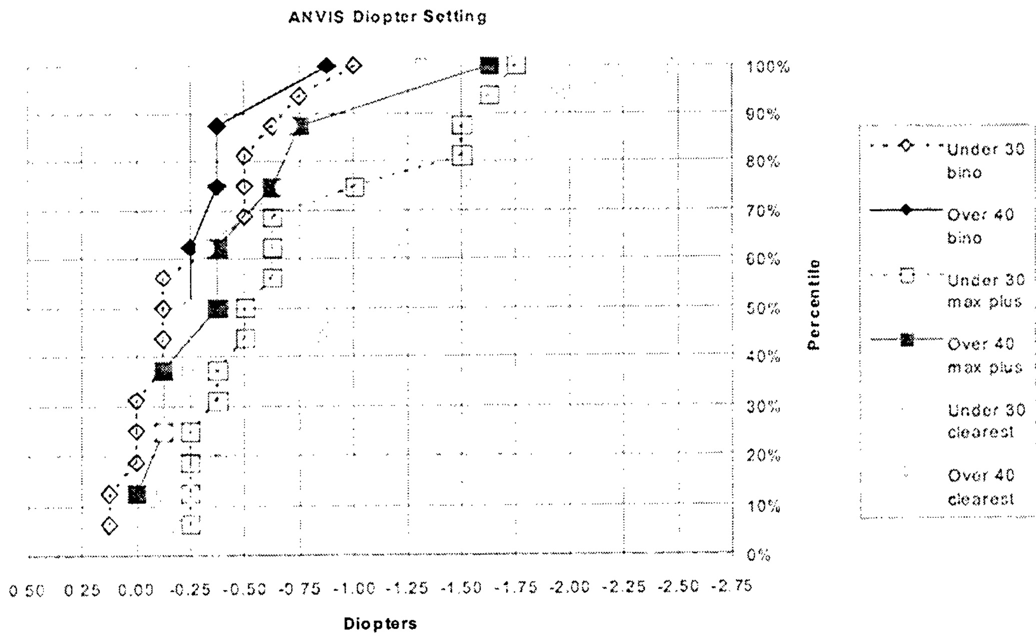

Figure 2. Sorted distribution of eyepiece diopter values for three different focusing techniques with ANVIS.

The plus lens blur points were determined monocularly with the participant reporting blur while viewing a resolution element that was two sizes larger (1.26 times larger) than the reported best monocular resolution. The minus lens blur points were determined binocularly. The mean plus and minus lens power blur points for the over 40 year old group with ANVIS was 0.48 diopters (standard deviation 0.26 diopters) for the plus lens blur point and –1.06 diopters (standard deviation 0.35 diopters) for the minus lens blur point. The mean plus and minus lens blur points for the under 30-year-old group with ANVIS was 0.48 diopters (standard deviation 0.27 diopters) for the plus lens blur point and –1.75 diopters (standard deviation 0.89 diopters). See also Appendix C. Note the increase in minus lens blur point and variance for the younger group, this represents additional reserve accommodation over the presbyopic, older subject group.

Unaided vision focus: The results of focusing procedures without ANVIS (unaided) were very similar to those obtained with ANVIS. The binocular focusing method showed the least minus or negative lens powers to stimulate accommodation than did the monocular techniques of Maximum Plus and Clearest Vision. Similarly, these differences were smaller with the older group than the younger participants. Figure 3 shows a sorted distribution of eyepiece diopter values averaged between the right and left eye versus percentile for the three different focusing techniques with unaided vision for the under 30 and over 40 year old groups. Note that the solid lines are the over 40 group and the dotted lines are the under 30 year old group.

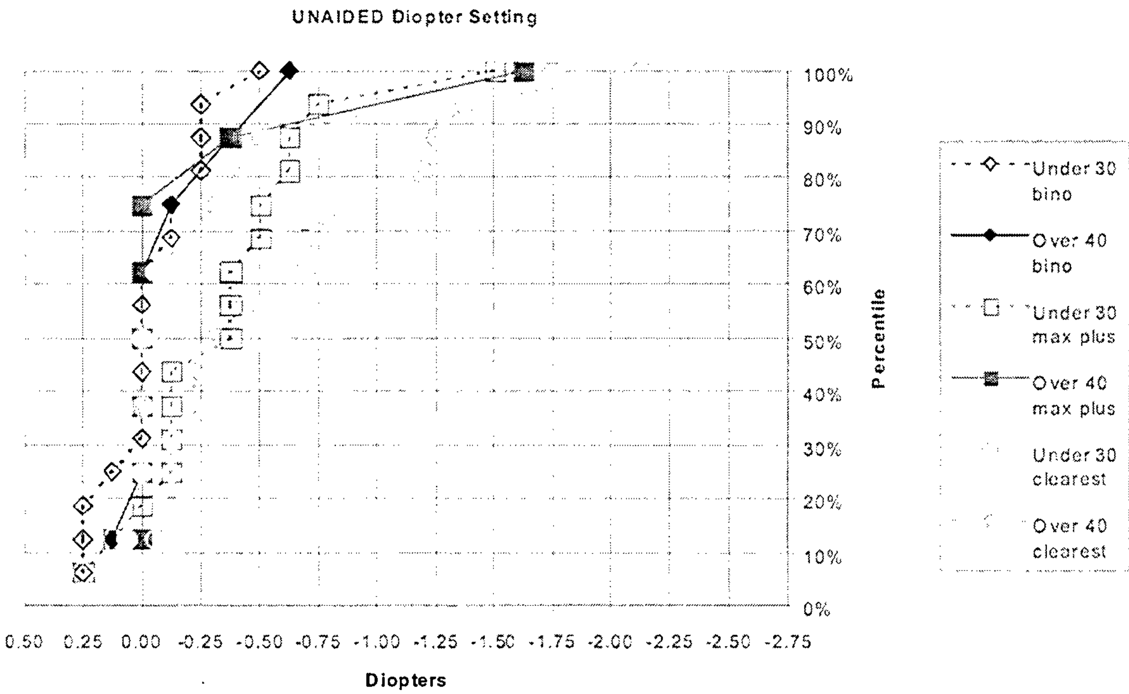

Figure 3. Sorted distribution of eyepiece diopter values for three different focusing techniques without ANVIS.

The mean plus and minus lens blur points using unaided vision for the over 40 group was 0.61 diopters (standard deviation 0.29 diopters) plus blur point and –1.06 diopters (standard deviation 0.62 diopters) minus blur point. For the under 30 year olds the means were 0.55 diopters (standard deviation 0.23 diopters) plus blur point and –1.22 diopters (standard deviation 0.47 diopters) minus blur point. See also Appendix C.

Comparisons between right and left eye focus adjustments (absolute values): For the over 40 year old group, the absolute differences between the right and left eye focus with or without ANVIS and for all three procedures were 0.25 diopter or less for all 8 participants except for one participant with 0.50 diopter difference using the Clearest Vision and Binocular focusing methods with ANVIS (see Table 1). Also note the small standard deviations (stdev).

Table 1.

Absolute difference between right eye (OD) and left eye (OS) for each method over 40 years old.

Diopters

N = 8	UNAIDED			ANVIS		
	Clearest Vision	Max Plus	Binocular	Clearest Vision	Max Plus	Binocular
mean	0.078	0.0625	0.125	0.156	.188	0.1875
stdev	0.1197	0.1157	0.1336	0.1797	.1157	0.1768
median	0	0	0.125	0.25	0.25	0.25
min	0	0	0	0	0	0
max	0.25	0.25	0.25	0.50	0.25	0.5

For the under 30 year olds, the mean absolute differences between the diopter values between the right and left eyes were greater than for the over 40 year olds for all procedures, with and without ANVIS. Also note the increase in the stdev for the clearest vision method compared to the other two focusing methods as listed in Table 2.

Table 2.

Absolute difference between right eye (OD) and left eye (OS) for each method under 30 years old.

Diopters

N =16	UNAIDED			ANVIS		
	Clearest Vision	Max Plus	Binocular	Clearest Vision	Max Plus	Binocular
mean	0.383	0.219	0.141	0.477	0.250	0.281
stdev	0.4446	0.2016	0.2410	0.5401	0.3291	0.2562
median	0.25	0.25	0	0.375	0.25	0.25
min	0	0	0	0	0	0
max	1.50	0.75	0.75	2.00	1.00	1.00

Comparisons between unaided and ANVIS diopter values: Using the under 30 age group with a sample size of 16, the diopter adjustment values for each procedure, with and without ANVIS, were compared for statistical differences using the t-test and assuming unequal variances. All three focusing methods showed significant differences at the 0.05 level of confidence (see Table 3).

Table 3.

Unaided versus ANVIS eyepiece focus values, under 30 year olds.

N =16 Procedure	Unaided Mean Diopter	ANVIS Mean Diopter	P-values
Clearest Vision	-0.60	-1.12	0.027*
Max Plus	-0.36	-0.75	0.030*
Binocular	-0.04	-0.28	0.021*

* Significant difference at the 0.05 confidence level

For the over 40 age group with only eight subjects, none of the comparisons between unaided and ANVIS showed a significant difference at the 0.05 level of confidence. However, the diopter values between unaided and ANVIS were approximately 0.25 diopter more minus with the ANVIS than without ANVIS for each method.

Comparisons between Max Plus and Binocular focusing techniques: Using the under 30 age group, the differences in the diopter values for the max plus and binocular techniques were compared for significant differences at the 0.05 level of confidence using the t-test and assuming unequal variances (see Table 4).

Table 4.

Max plus versus binocular focusing technique, under 30 year olds.

N = 16	Max Plus Diopter	Binocular Diopter	P-values
Unaided	-0.36	-0.04	0.011*
ANVIS	-0.75	-0.28	0.007*

* Significant difference at the 0.05 level of confidence

Comparisons between Max Plus and Clearest Vision focusing techniques: Using the under 30 age group, the differences in the diopter values for the max plus and clearest vision techniques were compared for significant differences at the 0.05 level of confidence using the t-test and assuming unequal variances (see table 5). There were no significant differences.

Table 5.

Max plus versus clearest vision focusing technique, under 30 year olds.

N = 16	Max Plus Diopter	Clearest Vision Diopter	P-values
Unaided	-0.36	-0.60	0.216
ANVIS	-0.75	-1.12	0.088

Comparisons between under 30 and over 40 year olds: Although the sample sizes were unequal between the under 30 and over 40 year olds, the eyepiece diopter values were compared between these two age groups for each focusing technique, with and without ANVIS. The probabilities for significant differences were calculated using the t-test, assuming unequal variances. Table 6 shows these comparisons.

Table 6.

Under 30 versus over 40 year olds for each focusing technique.

Focusing Technique	< 30 years old Diopter	> 40 years old Diopter	P-values
Clearest unaided	-0.60	-0.31	0.275
Max Plus unaided	-0.36	-0.25	0.639
Binocular unaided	-0.04	-0.12	0.418
Clearest ANVIS	-1.12	-0.48	0.014*
Max Plus ANVIS	-0.75	-0.50	0.292
Binocular ANVIS	-0.28	-0.31	0.804

* Significant difference at the 0.05 level of confidence

Discussion

Differences among procedures: As expected and shown with the younger group, the three different focusing techniques induced different amounts of excessive accommodation ranging from the least with the binocular focusing technique, followed by the monocular maximum plus and clearest vision methods, respectively. The monocular clearest vision method also showed the greatest range of values both for an individual and between individuals. This is because any diopter value between the users infinity focus value and their near point of accommodation distance would have the same acuity level. Using the counterclock wise rotation of the eyepieces to induce excessive plus power and a blur beyond infinity before rotating the lenses for clearest vision and no further will bias the focal point more towards the infinity setting. However, as shown, the users will still induce some negative lens powers because the procedure is conducted monocularly. When the counterclockwise method is used with a binocular focusing method, the

variability between focusing trials is less, and the least amount of minus power is induced while still obtaining the maximum resolution.

Differences with and without NVGs: Since the target was similarly matched for both luminance intensity and color, we did not expect to see a difference in the diopter values between the unaided and ANVIS focusing trials for each procedure. The green filter was spectrally similar to P22 green phosphor but peaks at the same wavelength as the P43 phosphor used in this study. However, there was a small but consistent difference of approximately 0.25 diopter more minus or less plus with ANVIS than without ANVIS. If this diopter shift were induced by differences in colors of the targets, with and without ANVIS, a color difference of approximately 40 nanometers would shift the eye diopter focus by approximately 0.25 diopter for the spectral range between 509 and 588 nanometers (Bedford and Wyszecki, 1947). Since there was not a significant difference in color of the target with or without ANVIS (Appendix B), the diopter difference is difficult to explain except the resolution was less with the goggles than with the unaided eye, which one would expect to show a greater depth of focus (range between diopter blur). However, this explanation does not hold using the data for the plus and minus blur points.

Differences between age groups: We used a smaller group for the over 40 than the younger participants because the reduced accommodation would reduce the variability for all the procedures for the older group. The younger group showed increased accommodation by a factor of approximately 4. As expected, for the monocular clearest vision and max plus procedures, the younger group induced more excessive minus power, which stimulated accommodation, whereas the older group showed less induced excessive minus power. However, with the binocular focusing technique, the difference in the effective eyepiece values was almost the same for the two age groups. The reason is that accommodation will fall near the angle of convergence or that convergence will control or limit accommodation when the eyes are aligned towards a distant object.

Implementing the binocular focusing method: The binocular focusing method for NVGs was first introduced almost 20 years ago by USAARL for the full-face plate AN/PVS-5s. It has been taught off and on by the U.S. Army since then. With the AN/PVS-5, the procedure was easier since the objective lenses were automatically focused at infinity when the lenses were turned fully counterclockwise. With ANVIS, because of the objective lens design, infinity focus was impossible for the factory or NVG maintainers to consistently achieve at the most counter-clockwise point. To add to the difficulty of focusing the ANVIS objective lenses, the focusing mechanism is coarse and not smooth. Therefore, the decision was made to allow the ANVIS objective lens to go slightly past infinity to both insure that the best focus was obtained, and to reduce the possible damage to the plastic objective lens assemblies. Thus, any focusing procedure that required the ANVIS objective lenses to be refocus at least twice would increase the time and complexity to achieve a good focus. With the newer fine focus objective lenses, the binocular focusing technique should be easier to learn and master with practice.

The second difficulty for teaching the binocular technique is how to describe the amount of blur the user should induce with the objective lens on the eye not being focused. The instructions

are to "induce blur such that fine details are lost but not general features". In reality, this means to blur the target about double the maximum resolution of the goggle. When a student is shown this level of blur by an instructor, they can usually achieve this level consistently afterwards. Resolution charts are excellent to use for the initial instructions, but the student needs to be able to perform the procedure using the out door method while viewing trees, poles, and any other features that contain fine features for accurate focus adjustments. To readjust the objective lenses, small light sources are the best and most sensitive targets, but not for the eyepiece focusing.

Figure 4 shows the approximate amount of objective lens rotation for the three lobe, F4949 ANVIS with two turns of focus range, and Figure 5 shows the 4 lobe, ANVIS-9 or ANVIS V3 with 3/4 turn of focus range. Note that these are only approximate and the objective lenses should be rotated clockwise as seen by the user to achieve a desired level of blur.

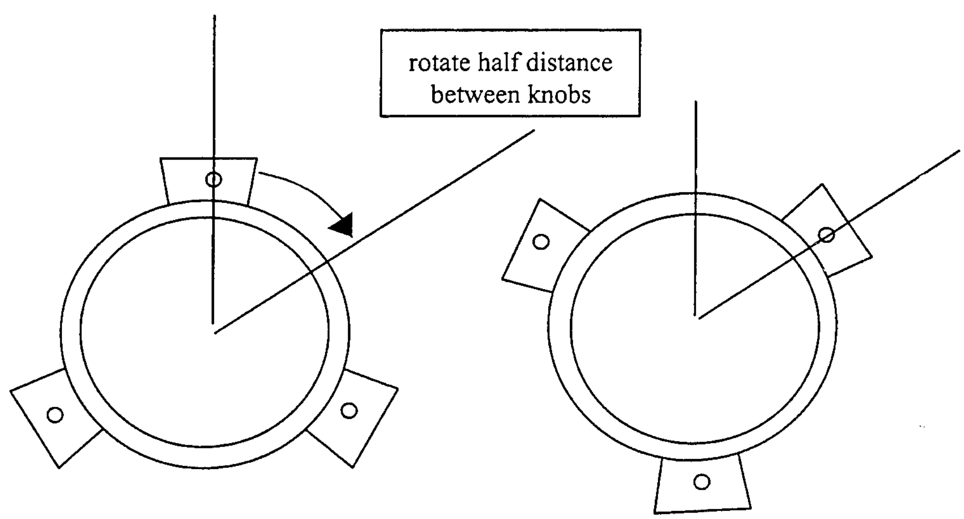

Figure 4. F4949 binocular focusing positioning of objective lens for 3 lobe, 2 turn type.

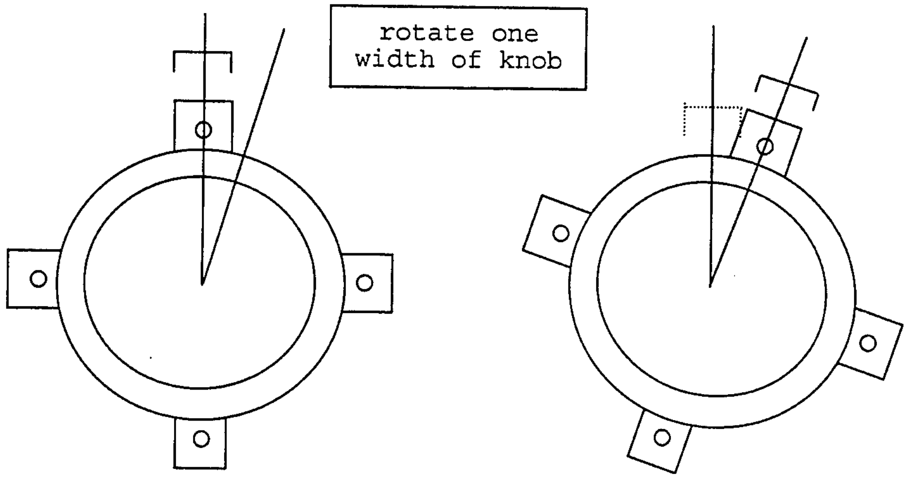

Figure 5. ANVIS-9 or V3 binocular focusing positioning of objective lens for 4 lobe, 3/4 turn focus range.

Conclusion

The procedure of placing the ANVIS in front of an ophthalmic phoropter provided a method to accurately determine the eyepiece diopter focus values in a relatively rapid manner for multiple measurements using three different focusing techniques. Using the two age groups that represented the younger and older NVG users, the data showed that the Binocular focusing technique provided the best acuity with the least minus power to simulate accommodation, followed by the two monocular techniques of Maximum Plus and Clearest Vision methods. For future night vision imaging systems that may have fixed focused eyepieces, the data suggest that a value of -0.50 diopter should provide comfortable vision with good acuity for most of the viewers, assuming the users are either emmetropic (do not need glasses) or are wearing corrective lenses.

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Note: USAARL reports may be viewed on the USAARL web site at http://www.usaarl.army.mil under the Technical Report menu.

Appendix A.

Definition and table of diopter values.

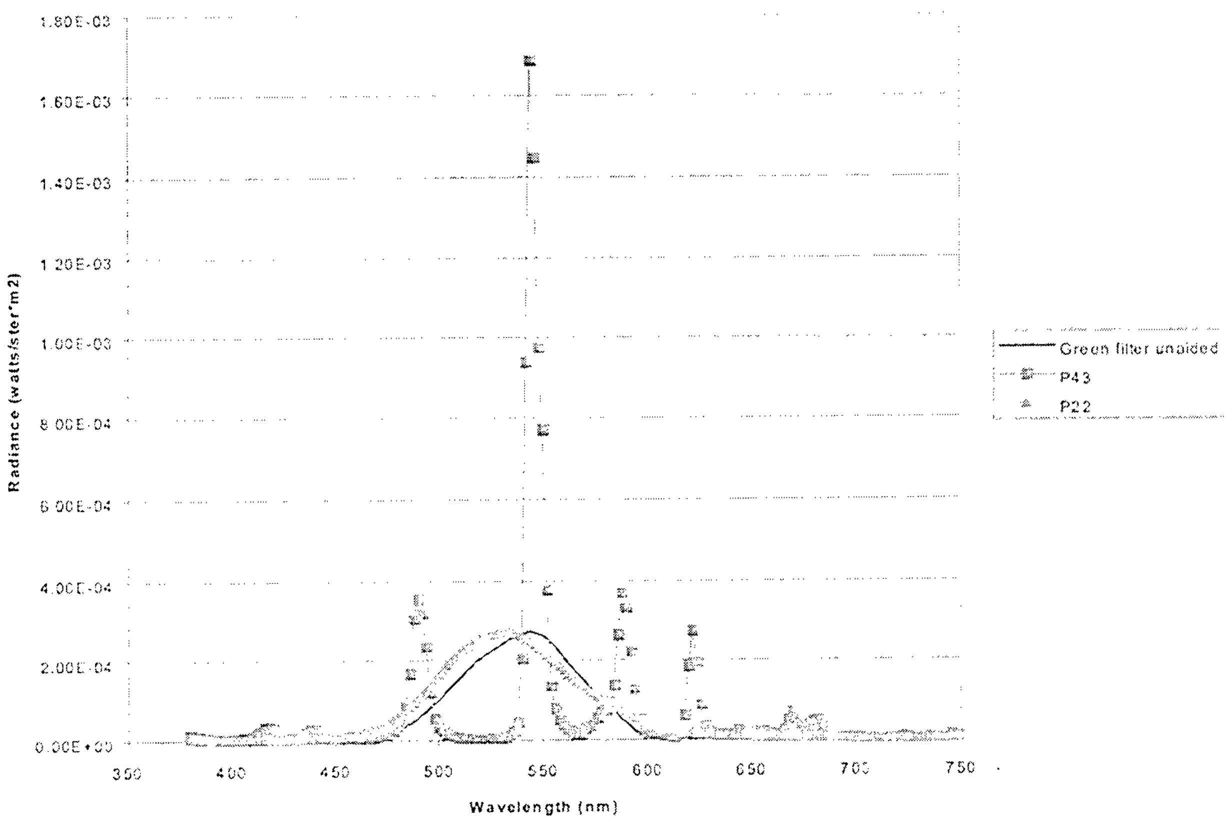
A diopter is an optical term to define the focal point of a lens or optical system. A diopter equals the reciprocal of the focal distance in meters: diopter = 1/f, where f is the focal distance in meters. A "positive" diopter (+) lens converges parallel light rays, and is used to correct for hyperopia (farsightedness). Positive lenses are also used to correct for presbyopia from reduced accommodation. A "negative" diopter (-) lens diverges parallel light rays, and is used to correct for myopia (nearsightedness). The following table calculates the focal distances in meters and feet for lens diopter values in 0.25 diopter steps to a value of 2.00 diopters.

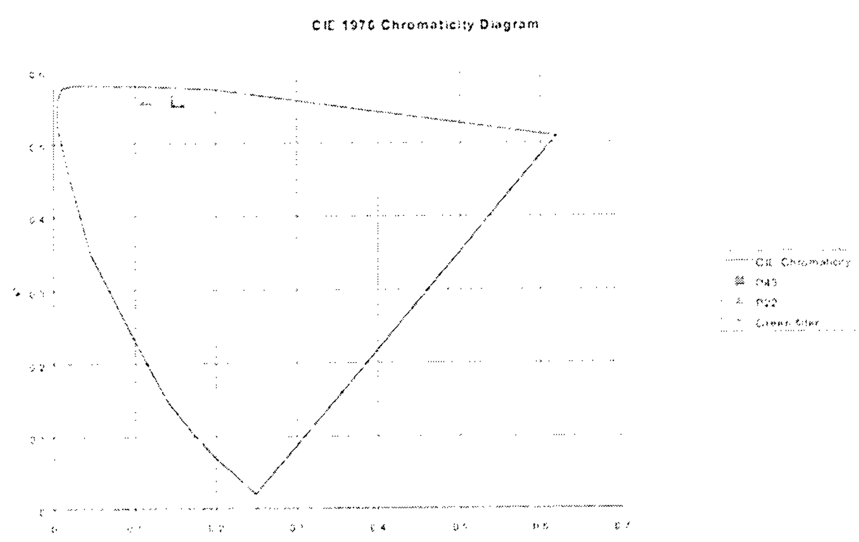
Diopters	Meters	Feet	Prism Diopters * of convergence
0.00	infinity	infinity	0.0^{Δ}
0.25	4.00	13.12	1.6^{Δ}
0.50	2.00	6.56	3.2^{Δ}
0.75	1.33	4.37	4.8^{Δ}
1.00	1.00	3.28	6.4^{Δ}
1.25	0.80	2.62	8.0^{Δ}
1.50	0.67	2.19	9.6^{Δ}
1.75	0.57	1.87	11.2^{Δ}
2.00	0.50	1.64	12.8^{Δ}

* Prism diopters are units of angular displacement of a ray such that one prism diopter is a displacement of 1 centimeter (cm) at one meter, measured on a tangent. The symbol for prism diopters is $^{\Delta}$. The column for prism diopters of convergence in the above table is calculated for an interpupillary distance of 6.4 cm.

Appendix B.

Spectral characteristics of ANVIS phosphors and green filter.





Note that the green filter over the incandescent projector light peaks very near the peak for the P43 phosphor used in this study, and the CIE color coordinates are very close to the P22 used in most fielded ANVIS.

Appendix C.

Test and summary data.

1. Subject data including age, NVG hours, corrective spectacles, refraction, distant lateral phoria, and monocular accommodation.
2. Summary of binocular focusing technique with and without ANVIS.
3. Summary of monocular maximum plus method with and without ANVIS.
4. Summary of monocular clearest vision procedure with and without ANVIS.

Subject data

Under 30 years old

	Age	NVG hours	Glasses 1 yes;0 no	Spherical Equivalent Manifest Refraction Rt eye	Spherical Equivalent Manifest Refraction Lt eye	prism diopters $^{\Delta}$ phoria at 20'	prism diopters $^{\Delta}$ phoria with -1.00 sph	diopters monocular accommodation	inches monocular accommodation
mean	26.6	62.1	0.13	-0.02	-0.03	0.31^{Δ}	-3.06^{Δ}	5.81	6.8"
stdev	1.75	107.4	0.342	0.346	0.375	2.36^{Δ}	3.66^{Δ}	1.74	not a linear value
median	27	20	0	0	0	1^{Δ}	-3^{Δ}	5.50	7.2"
min	23	0	0	-0.82	-1	-6^{Δ}	-12^{Δ}	10.00	3.9"
max	29	400	1	0.50	0.50	4^{Δ}	3^{Δ}	3.00	13.1"
number	16	16	16	16	16	16	16	15	15

Over 40 years old

	Age	NVG hours	Glasses 1 yes;0 no	Spherical Equivalent Manifest Refraction Rt eye	Spherical Equivalent Manifest Refraction Lt eye	prism diopters $^{\Delta}$ phoria at 20'	prism diopters $^{\Delta}$ phoria with -1.00 sph	diopters monocular accommodation	inches monocular accommodation
mean	49	1006	0.88	-0.09	-0.16	-0.56^{Δ}	-5.00^{Δ}	1.34	29.4"
stdev	5.04	771	0.354	0.831	1.143	1.591^{Δ}	4.062^{Δ}	0.823	not a linear value
median	46.5	750	1	-0.25	-0.0125	-0.25^{Δ}	-6^{Δ}	1.125	35.0"
min	44	200	0	-1.375	-1.62	-4^{Δ}	-9^{Δ}	0.50	78.7"
max	58	2000	1	1.00	1.50	1^{Δ}	1^{Δ}	2.75	14.3"
number	8	8	8	8	8	8	5*	8	8

* For the phoria at 20' with the -1.00 lens over their habitual, 3 of the over 40 group could not clear the Snellen 20/30 resolution phoria target.

Lateral phoria is in prism diopters $^{\Delta}$ where a minus value is esophoria and a plus value is exophoria.
Lateral phoria limits for flight standards are no greater than 8 esophoria or 8 exophoria (AR 40-501).

Summary of binocular focusing

DIOPTERS

Unaided

Over 40	O.D.	3 trial variable	O.S.	3 trial variable	VA Snellen	Lateral Phoria
mean	-0.125	0.094	-0.125	0.156	22.2	-0.88
stdev	0.2673	0.1294	0.2673	0.1294	2.70	3.87
median	0	0	0	0.25	21.75	0
min	-0.75	0	-0.50	0	18.3	-10
max	0	0.25	0.25	0.25	25.8	3
count	8	8	8	8	8	8

Under 30	O.D.	3 trial variable	O.S.	3 trial variable	VA Snellen	Lateral Phoria
mean	-0.083	0.150	0.000	0.250	22.1	-0.20
stdev	0.2938	0.1268	0.2113	0.2673	5.64	2.11
median	0	0.25	0	0.25	20.5	0
min	-0.75	0	-0.25	0	16.3	-4
max	0.25	0.25	0.25	1	36.5	4
Count	15	15	15	15	15	15

With ANVIS

Over 40	O.D.	3 trial variable	O.S.	3 trial variable	VA Snellen	Lateral Phoria
mean	-0.250	0.156	-0.375	0.156	28.4	-1.38
stdev	0.3536	0.1860	0.1890	0.1860	3.43	4.69
median	-0.25	0.125	-0.25	0.125	29	0
min	-1.00	0	-0.75	0.0	20.5	-12
max	0.25	0.50	-0.25	0.50	32.60	4.00
count	8	8	8	8	8	8

Under 30	O.D.	3 trial variable	O.S.	3 trial variable	VA Snellen	Lateral Phoria
mean	-0.313	0.250	-0.250	0.156	30.1	-0.31
stdev	0.3594	0.2236	0.4082	0.2213	5.53	2.06
median	-0.25	0.25	-0.25	0	29	0
min	-1.25	0	-1.00	0	18.3	-4
max	0	0.75	0.50	0.75	41	4
Count	16	16	16	16	16	16

The binocular focusing technique uses the max plus method, but both eyes are kept open.
The side that is not being focused for the eyepiece is blurred slightly with the objective lens.
The binocular method forces convergence towards infinity which also controls accommodation.
The 3 trial variable describes the range of values among the three trials for each condition for each subject.
VA Snellen is the equivalent Snellen denominator such as 20/22.2 and is determined binocularly.
Lateral phoria is in prism diopters where minus value is esophoria and plus value is exophoria.

Summary of maximum plus

Diopters

UNAIDED

Over 40	O.D.	3 trial variable	O.S.	3 trial variable	VA Snellen	Lateral Phoria
mean	-0.250	0.125	-0.250	0.125	23.5	-1.13^{Δ}
stdev	0.6124	0.1890	0.5345	0.1336	5.60	4.70^{Δ}
median	0	0	0	0.125	20.5	0^{Δ}
min	-1.75	0.00	-1.50	0.00	20.5	-12^{Δ}
max	0	0.5	0	0.25	36.5	4^{Δ}
count	8	8	8	8	8	8

Under 30	O.D.	3 trial variable	O.S.	3 trial variable	VA Snellen	Lateral Phoria
mean	-0.328	0.406	-0.391	0.266	23.6	-1.00^{Δ}
stdev	0.4446	0.5618	0.4375	0.1930	7.34	3.18^{Δ}
median	-0.25	0.25	-0.375	0.25	21.75	-0.5^{Δ}
min	-1.5	0	-1.5	0	16.3	-8^{Δ}
max	0.25	2	0.25	0.5	41	5

With ANVIS

Over 40	O.D.	3 trial variable	O.S.	3 trial variable	VA Snellen	Lateral Phoria
mean	-0.469	0.281	-0.531	0.281	29.2	-2.13^{Δ}
stdev	0.5892	0.2086	0.4713	0.2815	3.21	5.64^{Δ}
median	-0.375	0.25	-0.375	0.25	29	-1^{Δ}
min	-1.75	0	-1.50	0	23	-14^{Δ}
max	0	0.75	0	0.75	32.6	4^{Δ}
count	8	8	8	8	7*	8

Under 30	O.D.	3 trial variable	O.S.	3 trial variable	VA Snellen	Lateral Phoria
mean	-0.703	0.375	-0.797	0.453	30.6	-2.19^{Δ}
stdev	0.5417	0.3162	0.6139	0.2453	4.53	4.51^{Δ}
median	-0.50	0.25	-0.75	0.50	32.6	-1.5^{Δ}
min	-1.75	0.00	-2.00	0.00	20.5	-13^{Δ}
max	-0.25	1.25	0.25	1.00	36.5	6^{Δ}

* One subject had double vision from an excessive esophoria of 14 prism diopters.
For the maximum plus focusing method, plus lens power is increased to relax accommodation from the clear vision until the image is blurred past optical infinity. Plus lens power is reduced just to clearest vision. With the NVGs, the eyepiece lenses are rotated counterclockwise to a sustained blur and then to clear vision. This method is performed monocular for each eye.
The 3 trial variable describes the range of values among the three trials for each condition for each subject.
VA Snellen is the equivalent Snellen denominator such as 20/24.6 and determined binocularly.
Lateral phoria is in prism diopters where minus value is esophoria and plus value is exophoria.

Summary of clearest vision

Diopters

Unaided

Over 40	O.D.	3 trial variable	O.S.	3 trial variable	VA Snellen	Lateral Phoria
mean	-0.313	0.234	-0.328	0.125	24.2	-1.25 $^{\Delta}$
stdev	0.5951	0.4871	0.5966	0.3162	5.8	3.96 $^{\Delta}$
median	0	0.125	0	0	20.5	0 $^{\Delta}$
min	-1.75	0.00	-2.00	0.00	20.5	-12 $^{\Delta}$
max	0.25	2.00	0.00	1.25	36.5	2 $^{\Delta}$
number	16	16	16	16	16	16

Under 30	O.D.	3 trial variable	O.S.	3 trial variable	VA Snellen	Lateral Phoria
mean	-0.621	0.847	-0.613	0.556	24.6	-1.4 $^{\Delta}$
stdev	0.7328	0.8677	0.7715	0.5799	7.41	3.48 $^{\Delta}$
median	-0.50	0.50	-0.25	0.25	23	-1 $^{\Delta}$
min	-2.75	0	-2.25	0	16.3	-10 $^{\Delta}$
max	0.25	2.75	0.5	1.75	41	4 $^{\Delta}$
number	31	31	31	31	31	31

With ANVIS

Over 40	O.D.	3 trial variable	O.S.	3 trial variable	VA Snellen	Lateral Phoria
mean	-0.406	0.266	-0.531	0.250	29.5	-1.7 $^{\Delta}$
stdev	0.4553	0.2657	0.3750	0.2739	3.90	4.92 $^{\Delta}$
median	-0.25	0.25	-0.50	0.25	29	-1 $^{\Delta}$
min	-1.50	0	-1.50	0	20.5	-14 $^{\Delta}$
max	0	0.75	0	0.75	36.5	4 $^{\Delta}$
number	16	16	16	16	15	15

Under 30	O.D.	3 trial variable	O.S.	3 trial variable	VA Snellen	Lateral Phoria
mean	-1.070	0.828	-1.172	0.891	33.1	-3.8 $^{\Delta}$
stdev	0.7302	0.8043	0.9639	0.6808	10.6	5.60 $^{\Delta}$
median	-1.00	0.50	-1.00	0.75	32.6	-2.5 $^{\Delta}$
min	-2.75	0	-3.50	0	18.3	-20 $^{\Delta}$
max	0	3.75	0.50	2.50	82	6 $^{\Delta}$
number	32	32	32	32	32	30

The clearest vision method allows the user to oscillate the eyepiece lens powers between positive and negative powers to obtain the clearest image. This method is performed monocularly.
The 3 trial variable describes the range of values among the three trials for each condition and subject.
VA Snellen is the equivalent Snellen denominator such as 20/24.2 and is determined binocularly.
Lateral phoria is in prism diopters where minus value is esophoria and plus value is exophoria.

Diopters to blur from habitual*

Under 30 years old

	Unaided plus to blur	**Unaided** minus to blur	**ANVIS** plus to blur	**ANVIS** minus to blur
mean	0.55	-1.22	0.48	-1.75
stdev	0.228	0.473	0.271	0.89
median	0.50	-1.25	0.50	-1.50
min	0.25	-2.25	-0.125	-4.50
max	1.00	-0.50	0.75	-0.75
number	16	16	16	16

Over 40 years old

	Unaided plus to blur	**Unaided** minus to blur	**ANVIS** plus to blur	**ANVIS** minus to blur
mean	0.61	-1.06	0.48	-1.06
stdev	0.287	0.623	0.263	0.347
median	0.6875	-0.875	0.50	-1.00
min	0	-2.50	0.125	-1.50
max	0.875	-0.50	0.75	-0.50
number	8	8	8	8

*"Habitual" means the lens power of the spectacles for a person who wears glasses, or a value of zero if the person does not wear glasses for distant vision.

"Unaided plus to blur" is the average diopter value between the right and left eye of plus lens power required to blur the tri-bar elements two levels larger than the monocular best VA.

"Minus to blur" is the diopter value required to blur the tri-bar elements two levels larger than the binocular best VA.

Appendix D.

P values for right and left eye diopter values.

P values for comparisons between right and left eye diopter values for each procedure for the under 30 year old group

t-Test: Two-Sample Assuming Unequal Variances

P Values from t-test, two-sample assuming unequal variances, N = 16

Method	Unaided	with ANVIS
Clearest Vision	0.974	0.699
Max Plus	0.691	0.650
Binocular Technique	0.381	0.649

P values for comparisons between right and left eye diopter values for each procedure for the over 40 year old group

P Values from t-test, two-sample assuming unequal variances, N = 8

Method	Unaided	with ANVIS
Clearest Vision	0.941	0.404
Max Plus	1.00	0.818
Binocular Technique	1.00	0.397

Appendix E.

Study forms for data colletion

VISUAL SCREENING EXAM

(ANVIS) (UNAIDED) FOCUS METHODS (MAX PLUS)

(ANVIS) (UNAIDED) FOCUS METHODS (BINOCULAR)

Abbreviations in the data collection forms:

ACA	accommodation convergence association
AFVT	Armed Forces Vision Tester
bino	binocular
CYL	cylinder (lens prescription diopter power)
es or (s)	esophoria
ex or (x)	exophoria
L.E.or OS	left eye
LP	lateral prism
O.U.	both eyes or binocular
R.E.or OD	right eye
SPH	sphere (lens prescription diopter power)
VA	visual acuity

VISUAL SCREENING EXAM

Subject #______ Age:_____ NVG hours:________ Date:______

Spectacles (Yes) (No) Last Prescription date:_______

RX: O.D._______ Sph _____Cyl_____Axis Add______
O.S._______ Sph _____Cyl_____Axis Add______

AFVT - with glasses if required for distance #3, #2, #1

#3 VA R.E. line_____20/____ #2 Lateral Phoria #____ _____
FAR L.E. line_____20/_____ #1 Vertical Phoria #____ _____

LP = XO >11; VP = Rt Hyper >5, .5 steps

#5A Stereopsis thru line# ________

#7 Lateral Phoria @ Near #_______ ______ LP = XO >13

RETINOSCOPY P.D. __________

O.D. ______________________________
O.S. ______________________________

SUBJECTIVE REFRACTION (over habitual): (Green>Red)

O.D. _____________SPH. 20/
O.S. _____________SPH. 20/

Lateral Phoria @ Far __________ Vertical Phoria________

Lateral Phoria @ Far with -1.00 D __________

Lateral Phoria @ 50 cm __________

Lateral Phoria @ 50 cm +1.00 D ___________

Lateral Phoria @ 50 cm -1.00 D ____________

Calculated ACA ratios far minus _______ near plus ________

near minus_______ far/near ________

MONOCULAR ACCOMMODATION @ 50 cm to first sustained blur

	phoropter	Sub Rx	Distance		Accommodation
O.D.(-)	________ Sph +	________D	+2.00	=	________
O.S.(-)	________ Sph +	________D	+2.00	=	________

(ANVIS) (UNAIDED) FOCUS METHODS (MAX PLUS)

Subject #_______ Date _______ Schedule #_________

Clearest Vision- Random sequence for lens power

O.D. _________ _________ _________
O.S. _________ _________ _________

	trial #1	VA	trial #2	VA	trial #3	VA	bino VA	median Sph
O.D.	_________	_ _	_________	_ _	_________	_ _	__ __	_________
O.S.	_________	_ _	_________	_ _	_________	_ _		_________

distant lateral phoria

trial #1	trial #2	trial #3	average	median
____(es)(ex)	____(es)(ex)	____ (es)(ex)	____ (es)(ex)	____(s)(x)

Max Plus Method

	trial #1	VA	trial #2	VA	trial #3	VA	bino VA	median Sph
O.D.	_________	_ _	_________	_ _	_________	_ _	__ __	_________
O.S.	_________	_ _	_________	_ _	_________	_ _		_________

distant lateral phoria

trial #1	trial #2	trial #3	average	median
____(es)(ex)	____(es)(ex)	____ (es)(ex)	____ (es)(ex)	____(s)(x)

After all three trials:

* Plus lens to sustain blur (monocular) O.D._________ O.S.__________

** Minus lens to sustain blur (binocular) O.D.________ O.S.__________

Minus lens to sustain blur (monocular) O.D._________ O.S.__________

* Start with -0.50 Sph O.U.
** Start with Plano Sph O.U.

Comments and technique used:

(ANVIS) (UNAIDED) FOCUS METHODS (BINOCULAR)

Subject #______ Date ______ Schedule #________

Clearest Vision- Random sequence for lens power

O.D.	________	________	________
O.S.	________	________	________

	trial #1	VA	trial #2	VA	trial #3	VA	bino VA	median Sph
O.D.	________	_ _	________	_ _	________	_ _		________
O.S.	________	_ _	________	_ _	________	_ _	_ _	________

distant lateral phoria

trial #1	trial #2	trial #3	average	median
____(es) (ex)	____(es) (ex)	____ (es) (ex)	____ (es) (ex)	____(s) (x)

Binocular Method

Blur lens power with binocular method

	trial #1	trial #2	trial #3	average	median
O.D.	________	________	________	________	________
O.S.	________	________	________	________	________

	trial #1	VA	trial #2	VA	trial #3	VA	bino VA	median Sph
O.D.	________	_ _	________	_ _	________	_ _		________
O.S.	________	_ _	________	_ _	________	_ _	_ _	________

distant lateral phoria

trial #1	trial #2	trial #3	average	median
____(es) (ex)	____(es) (ex)	____ (es) (ex)	____ (es) (ex)	____(s) (x)